

## SURFACE ACOUSTIC WAVE DEVICE

## TECHNICAL FIELD

5 [0001]

The present invention relates to a surface acoustic wave device using a quartz substrate in which a device size is reduced, a Q value is increased, and a frequency-temperature characteristic is improved.

10

## BACKGROUND ART

[0002]

In recent years, a surface acoustic wave (hereinafter, SAW) device is widely utilized as a part for a terminal for mobile communication, a vehicle-mounted equipment, or the like, and it is strongly demanded to be downsized, have a high Q value, and be excellent in frequency stability.

[0003]

As a SAW device realizing these demands, there is a SAW device using an ST cut quartz substrate. The ST cut quartz substrate is a cut name of a quartz plate having a plane (XZ' plane) obtained by rotating an XZ plane from a crystal Z-axis in a counterclockwise direction by an angle of  $42.75^\circ$  utilizing a crystal X-axis as a rotation axis, and it utilizes a SAW (hereinafter, called ST cut quartz SAW) that is a (P+SV) wave propagated in a crystal X direction, called "Rayleigh wave".

An application of the ST cut quartz SAW device widely lies in a SAW resonator used as an oscillator, a filter for IF disposed between an RF stage and an IC in a mobile communication terminal, or the like.

5 [0004]

The reason why the ST cut quartz SAW device allows realization of a downsized device with a high Q value includes a point such that reflection of SAW can be utilized efficiently. An ST cut quartz SAW resonator shown in Fig. 13 will be explained  
10 as one example. The ST cut quartz SAW resonator has a structure that interdigital electrodes (hereinafter, called IDT) 102 having pluralities of electrode fingers mutually inserted are disposed on an ST cut quartz substrate 101 and grating  
15 reflectors 103a and 103b for reflecting SAW are disposed on both sides of the IDTs 102. Since the ST cut quartz SAW is a wave propagated along a surface of a piezoelectric substrate, it is efficiently reflected by the grating reflectors 103a and 103b and SAW energy can be sufficiently confined in the IDTs 102, so that a downsized device with a high Q value can be obtained.

20 [0005]

As an important factor in use of the SAW device, there is a frequency-temperature characteristic. In the ST cut quartz SAW, it is generally known that the primary temperature coefficient of the frequency-temperature characteristic of the  
25 SAW is zero, a characteristic thereof is expressed by a quadratic curve, and the SAW is excellent in frequency stability

because a frequency fluctuation amount is significantly reduced by making an adjustment so that a turnover temperature is positioned at the center in a usage temperature range.

[0006]

5           However, in the ST cut quartz SAW device, while the primary temperature coefficient is zero, the secondary temperature coefficient is relatively large such as  $-0.034$  (ppm/°C<sup>2</sup>). Accordingly, when the usage temperature range is expanded, the frequency fluctuation amount becomes extremely large.

10   [0007]

As an approach for solving the problem, there is a SAW device disclosed in Meirion Lewis, "Surface Skimming Bulk Wave, SSBW", IEEE Ultrasonics Symp. Proc., pp.744 to 752 (1977), and Japanese Examined Patent Publication No. 62-016050. As shown  
15 in Fig. 14, the feature of the SAW device is characterized in that a cut angle  $\theta$  of a rotation Y cut quartz substrate is set near a position rotated from a crystal Z-axis in a counterclockwise direction by an angle of  $-50^\circ$ , and a propagation direction of SAW is set to a perpendicular direction  
20 (a Z'-axis direction) to a crystal X-axis. Incidentally, when the cut angle is expressed by Euler angle,  $(0^\circ, \theta+90^\circ, 90^\circ)=(0^\circ, 40^\circ, 90^\circ)$  is obtained. The SAW device is characterized in that an SH wave propagated just below a surface of a piezoelectric substrate is exited by an IDT and oscillation energy is confined  
25 just below an electrode. A frequency-temperature

characteristic of the SAW device forms a cubic curve, and since a frequency fluctuation amount in a usage temperature range is significantly reduced, an excellent frequency-temperature characteristic is obtained.

5 [0008]

However, since the SH wave is a wave that fundamentally submerges in a substrate to advance, a reflecting efficiency of a SAW obtained by a grating reflector is poorer than that in the ST cut quartz SAW propagated along the piezoelectric  
10 substrate surface. Accordingly, there is a problem that it is difficult to realize a downsized SAW device with high Q. Since the prior Publication includes disclosure about application as a delay line which does not utilize reflection of a SAW but it does not propose any means for utilizing reflection of a SAW,  
15 it is said to be difficult to put the SAW device in a practical use.

[0009]

In order to solve the problem, Japanese Examined Patent Publication No. 01-034411 discloses a so-called multi-pair IDT  
20 type SAW resonator in which, as shown in Fig. 15, a cut angle  $\theta$  of a rotation Y cut quartz substrate is set in the vicinity of  $-50^\circ$  and multiple pairs, such as  $800 \pm 200$  pairs, of IDTs 112 is formed on a piezoelectric substrate 111 where a propagation direction of a SAW is set in a perpendicular direction (the  
25 Z'-axis direction) to a crystal X-axis, so that high Q is achieved by confining SAW energy by only reflection of the IDTs

112 themselves without utilizing a grating reflector.

[0010]

However, the multi-pair IDT type SAW resonator cannot obtain efficient energy confining effect as compared with a SAW resonator including a grating reflector. Since the number of IDT pairs required to obtain a high Q value is increased considerably to 800±200 pairs, there is a problem that a device size becomes larger than an ST cut quartz SAW resonator, so that a recent demand for size reduction cannot be satisfied.

10 [0011]

In the SAW resonator disclosed in Japanese Examined Patent Publication No. 01-034411, when a wavelength of a SAW excited by the IDT is represented as  $\lambda$ , a Q value can be increased by setting an electrode film thickness to 2% $\lambda$  or more, preferably 4% $\lambda$  or less. However, when a resonant frequency is 200 MHz, the Q value reaches saturation near 4% $\lambda$ , but the Q value obtained at that time becomes only about 20000 and only the Q value approximately equal to that in the ST cut quartz SAW resonator can be obtained in a comparison with the ST cut quartz SAW resonator. As its reason, it is thought that since, when the film thickness is in a range of 2% $\lambda$  or more to 4% $\lambda$  or less, a SAW are not concentrated sufficiently on a piezoelectric substrate surface, reflection cannot be utilized efficiently.

[Patent Document 1] Japanese Examined Patent Publication  
No. 62-016050

[Patent Document 2] Japanese Examined Patent Publication

[Nonpatent Document 1] Meirion Lewis, "Surface Skimming Bulk  
Wave, SSBW", IEEE Ultrasonics Symp.  
Proc., pp.744 to 752 (1977)

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#### DISCLOSURE OF THE INVENTION

#### PROBLEMS TO BE SOLVING BY THIS INVENTION

[0012]

A problem to be solved is that, when an ST cut quartz  
10 substrate is used as a piezoelectric substrate, the secondary  
temperature coefficient of a frequency-temperature  
characteristic is large as  $-0.034(\text{ppm}/^{\circ}\text{C}^2)$  so that a frequency  
fluctuation amount becomes considerably large practically.  
The structure of the SAW device disclosed in Japanese Examined  
15 Patent Publication No. 01-034411 includes a point that, since  
the number of pairs of IDTs has to be made considerably large,  
a device is increased in size.

#### MEANS FOR SLOVING THE PROBLEMS

20 [0013]

In order to solve the problem, the invention according  
to claim 1 of the present invention provides a SAW device  
comprising a piezoelectric substrate and an IDT that is formed  
on the piezoelectric substrate and is made from Al or alloy  
25 including Al as a main component, an excited wave being an SH  
wave, characterized in that the piezoelectric substrate is a

quartz flat plate where a cut angle  $\theta$  of a rotation Y cut quartz substrate is set in a range of  $-64.0^\circ < \theta < -49.3^\circ$  in a counterclockwise direction from a crystal Z-axis, and a propagation direction of a SAW is set to  $90^\circ \pm 5^\circ$  to a crystal X-axis, and when a wavelength of the SAW excited is represented as  $\lambda$ , an electrode film thickness  $H/\lambda$  standardized by a wavelength of the IDT is set to be  $0.04 < H/\lambda < 0.12$ .

[0014]

The invention according to claim 2 provides the SAW device, characterized in that a relationship between the cut angle  $\theta$  and the electrode film thickness  $H/\lambda$  satisfies

$$-1.34082 \times 10^{-4} \times \theta^3 - 2.34969 \times 10^{-2} \times \theta^2 - 1.37506 \times \theta - 26.7895 < H/\lambda < -1.02586 \times 10^{-4} \times \theta^3 - 1.73238 \times 10^{-2} \times \theta^2 - 0.977607 \times \theta - 18.3420.$$

[0015]

The invention according to claim 3 provides the SAW device, characterized in that, when an electrode finger width of electrode fingers constituting the IDT/(electrode finger width + space between electrode fingers) is defined as a line metalization ratio  $mr$ , a relationship between the cut angle  $\theta$  and a product  $H/\lambda \times mr$  of the electrode film thickness and the line metalization ratio satisfies

$$-8.04489 \times 10^{-5} \times \theta^3 - 1.40981 \times 10^{-2} \times \theta^2 - 0.825038 \times \theta - 16.0737 < H/\lambda \times mr < -6.15517 \times 10^{-5} \times \theta^3 - 1.03943 \times 10^{-2} \times \theta^2 - 0.586564 \times \theta - 11.0052.$$

[0016]

The invention according to claim 4 provides a SAW device

comprising a piezoelectric substrate and an IDT that is formed on the piezoelectric substrate and is made from Al or alloy including Al as a main component, an excited wave being an SH wave, characterized in that the piezoelectric substrate is a quartz flat plate where a cut angle  $\theta$  of a rotation Y cut quartz substrate is set to satisfy a range of  $-61.4^\circ < \theta < -51.1^\circ$  in a counterclockwise direction from a crystal Z-axis, and a propagation direction of a SAW is set to  $90^\circ \pm 5^\circ$  to a crystal X-axis, and when a wavelength of the SAW excited is represented as  $\lambda$ , an electrode film thickness  $H/\lambda$  standardized by a wavelength of the IDT is set to satisfy  $0.05 < H/\lambda < 0.10$ .

[0017]

The invention according to claim 5 provides the SAW device, characterized in that a relationship between the cut angle  $\theta$  and the electrode film thickness  $H/\lambda$  satisfies

$$-1.44605 \times 10^{-4} \times \theta^3 - 2.50690 \times 10^{-2} \times \theta^2 - 1.45086 \times \theta - 27.9464 < H/\lambda < -9.87591 \times 10^{-5} \times \theta^3 - 1.70304 \times 10^{-2} \times \theta^2 - 0.981173 \times \theta - 18.7946.$$

[0018]

The invention according to claim 6 provides the SAW device, characterized in that, when an electrode finger width of electrode fingers constituting the IDT/(electrode finger width + space between electrode fingers) is defined as a line metalization ratio  $mr$ , a relationship between the cut angle  $\theta$  and a product  $H/\lambda \times mr$  of the electrode film thickness and the line metalization ratio satisfies



$$-8.67632 \times 10^{-5} \times \theta^3 - 1.50414 \times 10^{-2} \times \theta^2 - 0.870514 \times \theta - 16.7678 < H/\lambda \times m_r < -5.92554 \times 10^{-5} \times \theta^3 - 1.02183 \times 10^{-2} \times \theta^2 - 0.588704 \times \theta - 11.2768.$$

[0019]

The inventions according to claims 7 to 14 provides the  
 5 SAW device, characterized in that the SAW device is any one of  
 a one-port SAW resonator, a two-port SAW resonator, a lateral  
 coupling type multi-mode filter, a vertical coupling type  
 multi-mode filter, a ladder type SAW filter, a transversal SAW  
 filter where an IDT propagating a SAW in both directions or in  
 10 one direction is disposed, or a SAW sensor.

[0020]

The invention according to claim 15 provides the SAW  
 device, characterized in that the SAW device has grating  
 reflectors on both sides of the IDT.

15 [0021]

The invention according to claim 16 provides a module  
 device or an oscillation circuit using the SAW device according  
 to any one of claims 1 to 15.

## 20 EFFECT OF THE INVENTION

[0022]

The SAW device according to claim 1 or 4 of the present  
 invention has a configuration that a rotation Y cut quartz  
 substrate whose cut angle  $\theta$  is in a range of  $-64.0^\circ < \theta < -49.3^\circ$ ,  
 25 preferably  $-61.4^\circ < \theta < -51.1^\circ$  is used, an SH wave excited such that

a propagation direction of a SAW is ( $90^\circ \pm 5^\circ$ ) to a crystal X-axis is used, an electrode material for the IDT and for the grating reflector is Al or alloy mainly containing Al, and the electrode film thickness  $H/\lambda$  standardized by a wavelength is set to satisfy  $0.04 < H/\lambda < 0.12$ , preferably  $0.05 < H/\lambda < 0.10$ . Since the present invention is configured to concentrate waves which originally submerge in a substrate to advance on a substrate surface to allow the grating reflector or the like to utilize reflection of a SAW efficiently, a SAW device, which is reduced in size, has a high Q value, and is excellent in frequency stability as compared with an ST cut quartz SAW device, can be provided.

[0023]

By satisfying the condition of the electrode film thickness  $H/\lambda$  and the cut angle  $\theta$  described in claim 2 or 5, a turnover temperature  $T_p$  ( $^\circ\text{C}$ ) can be set in a practical temperature range.

[0024]

By satisfying the condition of the product  $H/\lambda \times mr$  of the electrode film thickness and the line metalization ratio and the cut angle  $\theta$  described in claim 3 or 6, a turnover temperature  $T_p$  ( $^\circ\text{C}$ ) can be set in a practical temperature range.

[0025]

By using the SAW device of the various systems described in any one of claims 7 to 14, a SAW device, which is reduced

in size, has a high Q value, and is excellent in frequency stability can be provided.

[0026]

Since the SAW device described in claim 15 can confine  
5 energy of a SAW in an IDT sufficiently by disposing grating reflectors on both sides of the IDT, a downsized SAW device having a high Q value can be provided.

[0027]

Since the module device or the oscillation circuit  
10 described in claim 16 uses the SAW device according to the present invention, a downsized and high performance module device or an oscillation circuit can be provided.

#### BEST MODE FOR CARRYING OUT THE INVENTION

15 [0028]

The present invention will be explained below in detail based on embodiments shown in the drawings. Fig. 1(a) is a plan view of a SAW resonator according to the present invention, where an IDT 2 having positive electrode fingers and negative  
20 electrode fingers mutually inserted and grating reflectors 3a and 3b for reflecting a SAW positioned on both sides of the IDT 2 are arranged on a piezoelectric substrate 1. Input/output pads 4a and 4b of the IDT 2 and input/output terminals of a package 6 are electrically connected to each other by metal  
25 wires 5a and 5b and an opening portion of the package 6 is sealed by a lid air-tightly. As shown in Fig. 14, the piezoelectric

substrate 1 is a quartz flat plate where a cut angle  $\theta$  of a rotation Y cut quartz substrate is set near a position rotated from a crystal Z-axis in a counterclockwise direction by an angle of  $-50^\circ$ , and a propagation direction of a SAW is set to  
5 a approximately perpendicular direction ( $90^\circ \pm 5^\circ$ ) to a crystal X-axis, and the SAW to be excited is an SH wave. Electrode material for the IDT 2 and the grating reflectors 3a and 3b is Al or alloy including Al as a main component. Fig. 1(b) shows a section of the IDT 2, and when a wavelength of a SAW excited  
10 on the IDT 2 is represented as  $\lambda$  in the embodiment, an electrode film thickness is represented as a value  $H/\lambda$  standardized by the wavelength, and when an electrode finger width L of the electrode fingers constituting the IDT 2/(electrode finger width L + space S between electrode fingers) is defined as a  
15 line metalization ratio  $mr$ ,  $mr=0.60$  is satisfied.

[0029]

In the present invention, by setting the electrode film thickness  $H/\lambda$  to be larger than a conventional one in view of the defect in the conventional technique, a SAW are concentrated  
20 on a piezoelectric substrate surface, efficient utilization of reflection of a SAW by the grating reflectors is allowed, and SAW energy is confined in the IDT even in a reduced number of IDT pairs or grating reflectors so that a device size is reduced.

[0030]

25 Generally, in an optimal design for a SAW resonator, it

is important that a frequency-temperature characteristic is excellent,  $Q$  is high, and a capacitance ratio  $\gamma$  is small, namely, figure of merit ( $Q/\gamma$ ) is large. Various characteristics of the SAW resonator according to the present invention are examined here. Fig. 2 depicts various characteristics of a resonator obtained when  $-51^\circ$  rotation Y cut  $90^\circ$  X propagation quartz substrate ( $(0^\circ, 39^\circ, 90^\circ)$  in Euler angle expression) is used as the piezoelectric substrate 1, a resonance frequency is set to 315 MHz, the electrode film thickness  $H/\lambda$  is set to 0.06, the number of pairs of the IDT 2 is 100, and the numbers of the grating reflectors 3a and 3b are each 100 in the SAW resonator shown in Fig. 1. The  $Q$  value, the figure of merit, and the secondary temperature coefficient based upon an actual trial manufacture result are shown in Fig. 2(a), and the frequency-temperature characteristic based thereupon is shown in Fig. 2(b). For comparison, various characteristics of an ST cut quartz SAW resonator including a piezoelectric substrate having the same size as that of the SAW resonator according to the present invention is also shown as those in a conventional product.

[0031]

With reference to Fig. 2, when the SAW resonator according to the present invention and the conventional ST cut quartz SAW resonator are compared with each other, such large values that the  $Q$  value of the former is 1.8 times or more of the latter and the figure of merit in the former is about twice of the latter

are obtained. Regarding the frequency-temperature characteristic, a very excellent effect can be confirmed in the SAW resonator according to the present invention that about +25°C of the turnover temperature  $T_p$  can be obtained, and the frequency fluctuation amount due to a temperature is reduced to about 0.6 times of the conventional technique.

[0032]

The SAW resonator according to the present invention can reduce the size of the piezoelectric substrate while maintaining a  $Q$  value better than that in the ST cut quartz SAW resonator. This is because an amount of increase of a reflection amount of SAW at an IDT or a grating reflector to increase of the electrode film thickness  $H/\lambda$  of the SAW resonator according to the present invention is considerably larger than that in the ST cut quartz SAW resonator. That is, the SAW resonator according to the present invention can realize a high  $Q$  value in the number of pairs of IDTs or grating reflectors less than that in the ST cut quartz SAW resonator by making the electrode film thickness  $H/\lambda$  large.

[0033]

Fig. 3 shows a relationship between the electrode film thickness  $H/\lambda$  and the  $Q$  value in the SAW resonator according to the present invention, where a resonator design condition is equal to the one described above. It is understood from Fig. 3 that a value exceeding the  $Q$  value ( $= 15000$ ) of the ST cut quartz SAW resonator can be obtained in a range of  $0.04 < H/\lambda < 0.12$ .

Furthermore, a high Q value exceeding 20000 can be obtained by setting a range of  $0.05 < H/\lambda < 0.10$ .

[0034]

In a comparison of the Q values of the multi-pair IDT type SAW resonator shown in Japanese Examined Patent Publication No. 01-034411 and the SAW resonator according to the present invention, the Q value obtained in the patent application is a value when the resonant frequency is 207.561 (MHz), and the Q value is about 15000 when the resonant frequency is converted to 315 (MHz) that is the resonant frequency applied in the embodiment, where the Q value is approximately equivalent to that in the ST cut quartz SAW resonator. In a comparison of sizes of the resonators, the multi-pair IDT type SAW resonator described in the patent application requires  $800 \pm 200$  IDT pairs, but the present invention only requires a space accommodating 200 IDT pairs for both the IDT and the grating reflectors so that the present invention can be significantly reduced in size. Accordingly, by setting the electrode film thickness in a range of  $0.04 < H/\lambda < 0.12$  and providing grating reflectors to reflect a SAW efficiently, a SAW device, which is more downsized and higher in a Q value than the multi-pair IDT type SAW resonator disclosed in Japanese Examined Patent Publication No. 01-034411, can be realized.

[0035]

Next, Fig. 4 shows a relationship between the electrode film thickness  $H/\lambda$  and the secondary temperature coefficient

in the SAW resonator according to the present invention, where  
a resonator design condition is equal to the one described above.

It is understood from Fig. 4 that a value better than

$-0.034 (\text{ppm}/^{\circ}\text{C}^2)$  of the secondary temperature coefficient of the

5 ST cut quartz SAW resonator can be obtained in a range of  
 $0.04 < H/\lambda < 0.12$  where a high Q value can be obtained.

[0036]

By setting the electrode film thickness  $H/\lambda$  in a range  
of  $0.04 < H/\lambda < 0.12$  based on the above, a SAW device, which is more

10 downsized and higher in a Q value than the ST cut quartz SAW  
device and the SAW device disclosed in Japanese Examined Patent  
Publication No. 01-034411 and is excellent in frequency  
stability, can be provided.

[0037]

15 While only the case that the cut angle  $\theta$  is set to  $-51^{\circ}$   
has been described in the above, even if the cut angle  $\theta$  is  
changed in the SAW resonator according to the present invention,  
a film thickness dependency is not changed so much, so that an  
excellent Q value and a excellent secondary temperature  
20 coefficient can be obtained even at a cut angle shifted from  
 $-51^{\circ}$  by several degrees by setting the electrode film thickness  
in a range of  $0.04 < H/\lambda < 0.12$ .

[0038]

The SAW resonator according to the present invention  
25 takes a cubic temperature characteristic in a very wide



temperature range, but the temperature characteristic can be regarded as a quadratic characteristic in a specific narrow temperature range and a turnover temperature  $T_p$  in the temperature range varies depending on the electrode film

5 thickness and the cut angle. Therefore, no matter how excellent the frequency-temperature characteristic is, the frequency stability remarkably degrades when the turnover temperature  $T_p$  fluctuates to outside of the usage temperature range. In order to realize excellent frequency stability in a practical usage  
10 temperature range ( $-50^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ ), it is necessary to examine not only the secondary temperature coefficient but also the turnover temperature  $T_p$  in detail.

[0039]

Fig. 5(a) shows a relationship between the electrode film  
15 thickness  $H/\lambda$  and the turnover temperature  $T_p$ , obtained when the cut angle  $\theta$  is set to  $-50.5^{\circ}$  in the SAW resonator according to the present invention. As apparent from Fig. 5(a), when the electrode film thickness  $H/\lambda$  is made large, the turnover temperature  $T_p$  lowers and the relationship between the  
20 electrode film thickness  $H/\lambda$  and the turnover temperature  $T_p$  is represented by the following approximate expression.

$$T_p(H/\lambda) = -41825 \times (H/\lambda)^2 + 2855.4 \times (H/\lambda) - 26.42 \quad \cdots (1)$$

The approximate expression (1) can be applied in the cut angle near  $-50^{\circ}$ , except for its intercept.

25 [0040]

Fig. 5(b) shows a relationship between the cut angle  $\theta$  and the turnover temperature  $T_p$ , obtained when the electrode film thickness  $H/\lambda$  is set to 0.06 in the SAW resonator according to the present invention. As apparent from Fig. 5(b), when the absolute value of the cut angle  $\theta$  is reduced, the turnover temperature  $T_p$  lowers, and the relationship between the cut angle  $\theta$  and the turnover temperature  $T_p$  is represented by the following approximate expression.

$$T_p(\theta) = -43.5372 \times \theta - 2197.14 \quad \dots (2)$$

[0041]

Next, it is understood from the expression (1) and the expression (2) that, when the electrode film thickness  $H/\lambda$  is set to satisfy  $0.04 < H/\lambda < 0.12$ , it is sufficient to set the cut angle  $\theta$  in a range of  $-59.9^\circ \leq \theta \leq -48.9^\circ$  for setting the turnover temperature  $T_p$  in the practical usage temperature range ( $-50^\circ\text{C}$  to  $+125^\circ\text{C}$ ).

[0042]

When both the electrode film thickness  $H/\lambda$  and the cut angle  $\theta$  are taken in consideration, the turnover temperature  $T_p$  is represented by the following approximate expression utilizing the expression (1) and the expression (2).

$$T_p(H/\lambda, \theta) = T_p(H/\lambda) + T_p(\theta) = -41825 \times (H/\lambda)^2 + 2855.4 \times (H/\lambda) - 43.5372 \times \theta - 2223.56 \quad \dots (3)$$

In order to set the turnover temperature  $T_p$  in the usage temperature range ( $-50^\circ\text{C}$  to  $+125^\circ\text{C}$ ), the electrode film

thickness  $H/\lambda$  and the cut angle  $\theta$  can be set in a range represented by the following expression from the approximate expression (3).

$$0.9613 \leq -18.498 \times (H/\lambda)^2 + 1.2629 \times (H/\lambda) - 0.019255 \times \theta \leq 1.0387 \cdots (4)$$

5 [0043]

Thus, in the present invention, the rotation Y cut quartz substrate where the cut angle  $\theta$  is in a range of  $-59.9^\circ \leq \theta \leq -48.9^\circ$  is used, the SH wave excited such that a propagation direction of a SAW is a direction approximately perpendicular to the X-axis is used, the electrode material for the IDT and the grating reflector is Al or alloy including Al as a main component, and the electrode film thickness  $H/\lambda$  is set to satisfy  $0.04 < H/\lambda < 0.12$ . With this configuration, a SAW device, which is more downsized and higher in a Q value than the ST cut quartz SAW device and is excellent in frequency stability, can be realized.

[0044]

An optimal condition will be examined here. It is preferable that the electrode film thickness  $H/\lambda$  is set in a range of  $0.05 < H/\lambda < 0.10$  where the Q value of 20000 or more can be obtained as shown in Fig. 3. Furthermore, it is preferable that the cut angle  $\theta$  is set in a range of  $-55.7^\circ \leq \theta \leq -50.2^\circ$  in order to set the turnover temperature  $T_p$  in a more practical usage temperature range ( $0^\circ\text{C}$  to  $+70^\circ\text{C}$ ). Furthermore, it is preferable that the cut angle  $\theta$  and the electrode film thickness

$H/\lambda$  are set in a range defined by the following expression obtained from the approximate expression (3).

$$0.9845 \leq -18.518 \times (H/\lambda)^2 + 1.2643 \times (H/\lambda) - 0.019277 \times \theta \leq 1.0155 \dots (5)$$

[0045]

5 In the above explanation, a relational expression between the electrode film thickness  $H/\lambda$  and the cut angle  $\theta$  where the turnover temperature  $T_p$  falls in the practical usage temperature range has been derived from the relationship between the electrode film thickness  $H/\lambda$  and the turnover  
10 temperature  $T_p$  obtained when the cut angle  $\theta$  shown in Fig. 5(a) is set to  $-50.5^\circ$  and the relationship between the cut angle  $\theta$  and the turnover temperature  $T_p$  obtained when the electrode film thickness  $H/\lambda$  shown in Fig. 5(b) is set to 0.06. More detailed conditions were found by an experiment performed with an  
15 expanded range of the cut angle  $\theta$ , and they will be explained below.

[0046]

Fig. 6 shows a relationship between the cut angle  $\theta$  of a quartz substrate and the electrode film thickness  $H/\lambda$  obtained  
20 when the turnover temperature  $T_p$  ( $^\circ\text{C}$ ) satisfies  $T_p = -50, 0, +70$ , and  $+125$  in the SAW resonator, where approximate expressions for respective  $T_p$  characteristics are as follows:

$$T_p = -50 (^\circ\text{C}) : H/\lambda \doteq -1.02586 \times 10^{-4} \times \theta^3 - 1.73238 \times 10^{-2} \times \theta^2 - 0.977607 \times \theta - 18.3420$$

$$25 \quad T_p = 0 (^\circ\text{C}) : H/\lambda \doteq -9.87591 \times 10^{-5} \times \theta^3 - 1.70304 \times 10^{-2} \times \theta^2 - 0.981173 \times \theta - 18.$$

7946

$T_p = +70 (^{\circ}\text{C}) : H/\lambda \doteq -1.44605 \times 10^{-4} \times \theta^3 - 2.50690 \times 10^{-2} \times \theta^2 - 1.45086 \times \theta - 27.$

9464

$T_p = +125 (^{\circ}\text{C}) : H/\lambda \doteq -1.34082 \times 10^{-4} \times \theta^3 - 2.34969 \times 10^{-2} \times \theta^2 - 1.37506 \times \theta -$

5 26.7895

[0047]

It is understood from Fig. 6 that the cut angle  $\theta$  and the electrode film thickness  $H/\lambda$  can be set to satisfy a region surrounded by curves of  $T_p = -50^{\circ}\text{C}$  and  $T_p = +125^{\circ}\text{C}$ , namely,

10  $-1.34082 \times 10^{-4} \times \theta^3 - 2.34969 \times 10^{-2} \times \theta^2 - 1.37506 \times \theta - 26.7895 < H/\lambda < -1.025$

$86 \times 10^{-4} \times \theta^3 - 1.73238 \times 10^{-2} \times \theta^2 - 0.977607 \times \theta - 18.3420$ , in order to set

the turnover temperature  $T_p (^{\circ}\text{C})$  to satisfy  $-50 \leq T_p \leq +125$  which

is a practical range. It is necessary to set the range of the electrode film thickness  $H/\lambda$  at this time to satisfy

15  $0.04 < H/\lambda < 0.12$  which allows a characteristic better than that

of the conventional ST cut quartz device and set the range of

the cut angle  $\theta$  to satisfy  $-64.0 < \theta < -49.3$  that corresponds to

a range from a point A to a point B shown in Fig. 6.

[0048]

20 Further, in an examination about the more optimal

condition, it is preferable that the turnover temperature  $T_p$

( $^{\circ}\text{C}$ ) is set to satisfy  $0 \leq T_p \leq +70$  that corresponds to a further

practical usage temperature range. The cut angle  $\theta$  and the

electrode film thickness  $H/\lambda$  can be set to satisfy a region

25 surrounded by curves of  $T_p = 0^{\circ}\text{C}$  and  $T_p = +70^{\circ}\text{C}$  shown in Fig. 6,

namely,

$$-1.44605 \times 10^{-4} \times \theta^3 - 2.50690 \times 10^{-2} \times \theta^2 - 1.45086 \times \theta - 27.9464 < H/\lambda < -9.87591 \times 10^{-5} \times \theta^3 - 1.70304 \times 10^{-2} \times \theta^2 - 0.981173 \times \theta - 18.7946,$$

in order to set

$T_p$  ( $^{\circ}\text{C}$ ) in the range described above. It is also preferable

5 that the electrode film thickness  $H/\lambda$  is set to satisfy a range

of  $0.05 < H/\lambda < 0.10$  where the  $Q$  value of 20000 or more can be

obtained. Furthermore, it is necessary to set the cut angle

$\theta$  to satisfy  $-61.4 < \theta < -51.1$  that corresponds to a range from a

point C to a point D shown in Fig. 6(a) in order to set the

10 electrode film thickness in the range described above and set

the turnover temperature  $T_p$  ( $^{\circ}\text{C}$ ) to a range of  $0 \leq T_p \leq +70$ .

[0049]

As the result of the detailed examination explained above,  
it has been found that an excellent temperature characteristic

15 where the  $Q$  value is larger than that in the ST cut quartz SAW

device can be obtained, and the turnover temperature  $T_p$  can be

set in a practical usage temperature range by using a rotation

Y cut quartz substrate where the cut angle  $\theta$  satisfies

$-64.0^{\circ} < \theta < -49.3^{\circ}$ , preferably  $-61.4^{\circ} < \theta < -51.1^{\circ}$ , using an SH wave

20 excited such that a propagation direction of a SAW is a direction

approximately perpendicular to the X-axis, forming an electrode

material for the IDT or the grating reflector from Al or alloy

mainly including Al, and setting the electrode film thickness

$H/\lambda$  to satisfy  $0.04 < H/\lambda < 0.12$ , preferably  $0.05 < H/\lambda < 0.10$ .

25 [0050]

While the example where the line metalization ratio  $mr$  of the IDT is fixed at 0.60 has been explained above, an example where the  $T_p$  characteristic is obtained when the line metalization ratio is included in a variable is examined below.

5 [0051]

Fig. 7 shows a relationship between the product  $H/\lambda \times mr$  of the electrode film thickness and the line metalization ratio and the turnover temperature  $T_p$ . A vertical axis indicates the turnover temperature  $T_p$  ( $^{\circ}\text{C}$ ), while a horizontal axis indicates  
 10 the product  $H/\lambda \times mr$  of the electrode film thickness and the line metalization ratio. At this time, the cut angle  $\theta$  of the quartz substrate is set to  $-51.5^{\circ}$ . As shown in Fig. 7, it is understood that the turnover temperature  $T_p$  lowers according to increase of the value of the product  $H/\lambda \times mr$  of the electrode film  
 15 thickness and the line metalization ratio.

[0052]

Next, Fig. 8 shows a relationship between the cut angle  $\theta$  of the quartz substrate and the product  $H/\lambda \times mr$  of the electrode film thickness and the line metalization ratio obtained when  
 20 the turnover temperature  $T_p$  ( $^{\circ}\text{C}$ ) is  $-50$ ,  $0$ ,  $+70$ , and  $+125$ . Approximate expressions for respective  $T_p$  characteristics are as follows:

$$T_p = -50 (^{\circ}\text{C}) : H/\lambda \times mr \doteq -6.15517 \times 10^{-5} \times \theta^3 - 1.03943 \times 10^{-2} \times \theta^2 - 0.586564 \times \theta - 11.0052$$

$$25 \quad T_p = 0 (^{\circ}\text{C}) : H/\lambda \times mr \doteq -5.92554 \times 10^{-5} \times \theta^3 - 1.02183 \times 10^{-2} \times \theta^2 - 0.588704 \times \theta$$

-11.2768

$T_p=+70(^{\circ}\text{C}): H/\lambda \times mr \doteq -8.67632 \times 10^{-5} \times \theta^3 - 1.50414 \times 10^{-2} \times \theta^2 - 0.870514$   
 $\times \theta - 16.7678$

$T_p=+125(^{\circ}\text{C}): H/\lambda \times mr \doteq -8.04489 \times 10^{-5} \times \theta^3 - 1.40981 \times 10^{-2} \times \theta^2 - 0.825038$   
5  $\times \theta - 16.0737$   
[0053]

It is understood from Fig. 8 that the cut angle  $\theta$  and the product  $H/\lambda \times mr$  of the electrode film thickness and the line metalization ratio can be set to satisfy a region surrounded  
10 by curves of  $T_p=-50^{\circ}\text{C}$  and  $T_p=+125^{\circ}\text{C}$ , namely,  
 $-8.04489 \times 10^{-5} \times \theta^3 - 1.40981 \times 10^{-2} \times \theta^2 - 0.825038 \times \theta - 16.0737 < H/\lambda \times mr < -6$   
 $.15517 \times 10^{-5} \times \theta^3 - 1.03943 \times 10^{-2} \times \theta^2 - 0.586564 \times \theta - 11.0052$ , in order to  
set the turnover temperature  $T_p (^{\circ}\text{C})$  to satisfy  $-50 \leq T_p \leq +125$  that  
is a practical range. At this time, it is necessary to set the  
15 range of the electrode film thickness  $H/\lambda$  to  $0.04 < H/\lambda < 0.12$  where  
a characteristic better than that in the conventional ST cut  
quartz device can be obtained, and set the range of the cut angle  
 $\theta$  to  $-64.0 < \theta < -49.3$ .

[0054]

20 The cut angle  $\theta$  and the product  $H/\lambda \times mr$  of the electrode  
film thickness and the line metalization ratio can be set to  
satisfy a region surrounded by curves of  $T_p=0^{\circ}\text{C}$  and  $T_p=+70^{\circ}\text{C}$   
shown in Fig. 8, namely,

$-8.67632 \times 10^{-5} \times \theta^3 - 1.50414 \times 10^{-2} \times \theta^2 - 0.870514 \times \theta - 16.7678 < H/\lambda \times mr < -5$   
25  $.92554 \times 10^{-5} \times \theta^3 - 1.02183 \times 10^{-2} \times \theta^2 - 0.588704 \times \theta - 11.2768$ , in order to



set the turnover temperature  $T_p$  ( $^{\circ}\text{C}$ ) to satisfy  $0 \leq T_p \leq +70$ , which is a more practical usage temperature range. At this time, it is desirable that the electrode film thickness  $H/\lambda$  is set to satisfy  $0.05 < H/\lambda < 0.10$  where the  $Q$  value of 20000 or more can be obtained, and it is desirable that the cut angle  $\theta$  is set to satisfy  $-61.4 < \theta < -51.1$ , in order to set the electrode film thickness to the range described above and set the turnover temperature  $T_p$  ( $^{\circ}\text{C}$ ) in a range of  $0 \leq T_p \leq +70$ .

[0055]

While only a one-port SAW resonator such as the one shown in Fig. 1 has been described hitherto, the present invention can be applied to SAW devices other than the one-port SAW resonator. Structures of various SAW devices will be explained below.

[0056]

Fig. 9 shows a two-port SAW resonator where IDTs 32 and 33 are disposed along a propagation direction of a SAW on a piezoelectric substrate 31, and grating reflectors 34a and 34b are disposed on both sides of the IDTs 32 and 33, where a high  $Q$  value can be realized like the one-port SAW resonator.

[0057]

Fig. 10 shows a dual mode SAW (DMS) filter utilizing acoustic coupling of SAW resonators as one system for a resonator filter, where Fig. 10(a) shows a lateral coupling type DMS filter where SAW resonators 42 are disposed on a

piezoelectric substrate 41 in proximity to each other in parallel with a propagation direction, and Fig. 10(b) shows a two-port vertical coupling type DMS filter where SAW resonators including IDTs 52 are disposed on the piezoelectric substrate 51 along a propagation direction of a SAW. The lateral coupling type DMS filter utilizes perpendicular acoustic coupling to the propagation direction and the two-port vertical coupling type DMS filter utilizes horizontal acoustic coupling to the propagation. These DMS filters have a feature that a flat pass band and excellent out-of-band suppressing degree can be obtained. The two-port vertical coupling type DMS filter can be connected with a SAW resonator for highly attenuating the vicinity of a pass band. The present invention can be applied to a multi-mode SAW filter utilizing a high-order mode or a multi-mode SAW filter where acoustic coupling is performed both in a perpendicular direction and in a horizontal direction to a propagation direction.

[0058]

Fig. 11 shows a ladder-type SAW filter configured by arranging a plurality of one-port SAW resonators 62 on a piezoelectric substrate 61 in a ladder shape configured by series, parallel, and series as another system of the resonator filters. The ladder-type SAW filter can obtain a filter characteristic where an attenuation slope of the vicinity of the pass band is sharper than that in the DMS filter.

[0059]

Figs. 12 show transversal SAW filters, where Fig. 12(a) shows one of the transversal SAW filters where an input IDT 72 and an output IDT 73 are disposed on a piezoelectric substrate 71 with a predetermined spacing along a propagation direction of a SAW. The IDTs 72 and 73 propagate a SAW in both directions. A shielding electrode 74 can be provided for preventing influence of a direct wave between input and output terminals or sound absorbing materials 75 can be applied on both ends of the piezoelectric substrate 71 for suppressing unnecessary reflected waves from end faces of the substrate. The transversal SAW filter is frequently used as an IF filter because an amplitude characteristic and a phase characteristic thereof can be designed independently from each other and an out-of-band suppressing degree is high.

15 [0060]

The transversal SAW filter has a problem that insertion loss of a filter becomes large because a SAW is propagated equally to right and left along a propagation direction. As a method for solving the problem, there is a transversal SAW filter where so-called single phase uni-directional transducers (SPUDT) 82 and 83 where excitation of a SAW is made uni-directional by changing an electrode finger arrangement or an electrode finger width to weight excitation and reflection of a SAW are disposed, as shown in Fig. 12(b). Since the excitation of a SAW is made uni-directional, a low loss filter characteristic can be obtained. As other structures, there are

so-called reflection bank type transversal SAW filters where a grating reflector is disposed between exciting electrodes of an IDT and the like.

[0061]

5           In the various SAW devices described above, it is apparent that an advantage similar to that obtained in the present invention can be obtained by using a quartz flat plate as a piezoelectric substrate where the cut angle  $\theta$  of the rotation Y cut quartz substrate is set to satisfy a range of  
10    $-64.0^\circ < \theta < -49.3^\circ$ , preferably  $-61.4^\circ < \theta < -51.1^\circ$ , in a counterclockwise direction from the crystal Z-axis, and a propagation direction of an surface acoustic wave is set to  $90 \pm 5^\circ$  to the crystal X-axis and setting the electrode film thickness  $H/\lambda$  to satisfy a range of  $0.04 < H/\lambda < 0.12$ , preferably  
15    $0.05 < H/\lambda < 0.10$ .

[0062]

          In the above described SAW device, it is apparent that an advantage similar to that obtained in the present invention can be obtained even when such a protective film as a protective  
20   film made from  $\text{SiO}_2$  or the like, a protective film obtained by anode-oxidizing Al, or the like is formed on an IDT or a grating reflector, or a closely adhesive layer or another metal thin film for improvement in power withstanding is formed on an upper or lower portion of an Al electrode. It goes without saying  
25   that the SAW device according to the present invention is

applicable to a sensor device or a module device, an oscillation circuit, or the like. Since the capacity ratio  $\gamma$  can be reduced by using the SAW device according to the present invention in a voltage control SAW oscillator (VCSO) or the like, a variable  
5 width of a frequency can be taken larger.

[0063]

The SAW device according to the present invention can have a structure other than the structure where the SAW chip and the package are wire-bonded to each other, such as the one shown  
10 in Fig. 1, and it can have a flip-chip bonding (FCB) structure where an electrode pad of a SAW chip and a terminal of a package are connected via a metal bump, a CSP (chip size package) structure where a SAW chip is bonded on a wiring substrate in a flip-chip manner and surroundings of the SAW chip is  
15 resin-sealed, a WLCSP (wafer level chip size package) structure where a package or a wiring substrate is made unnecessary by forming a metal layer or a resin layer on a SAW chip, or the like. An AQP (all quartz package) structure where stacking and sealing are performed in a state that a quartz device is  
20 sandwiched by quartzes or glass substrates can be adopted. Since the AQP structure is a structure where sandwiching is simply performed utilizing quartzes or glass substrates, no package is required, thinning can be performed, and out gas due to adhesive can be reduced by adopting low melting point glass  
25 sealing or direct bonding, so that an advantage such as an excellent aging characteristic can be achieved.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0064]

[Fig. 1] Figs. 1 are diagrams for explaining a SAW resonator  
5 according to the present invention, where Fig. 1(a) is a plan  
view, and Fig. 1(b) is a sectional view of an IDT.

[Fig. 2] Figs. 2 show comparisons between the SAW resonator  
according to the present invention and a conventional product,  
where Fig. 2(a) is a diagram showing a comparison regarding a  
10 Q value, a figure of merit, and a secondary temperature  
coefficient, and Fig. 2(b) is a diagram showing a comparison  
regarding a frequency-temperature characteristic.

[Fig. 3] Fig. 3 is a diagram showing a relationship between  
an electrode film thickness  $H/\lambda$  and a Q value in the SAW resonator  
15 according to the present invention.

[Fig. 4] Fig. 4 is a diagram showing a relationship between  
the electrode film thickness  $H/\lambda$  and a secondary temperature  
coefficient in the SAW resonator according to the present  
invention.

20 [Fig. 5] Fig. 5(a) is a diagram showing a relationship  
between the electrode film thickness  $H/\lambda$  and a turnover  
temperature  $T_p$  in the SAW resonator according to the present  
invention, and Fig. 5(b) is a diagram showing a relationship  
between a cut angle  $\theta$  and the turnover temperature  $T_p$  therein.

25 [Fig. 6] Fig. 6 is a diagram showing a relationship between  
the cut angle  $\theta$  and the electrode film thickness  $H/\lambda$  obtained

when the turnover temperature  $T_p$  ( $^{\circ}\text{C}$ ) satisfies  $T_p = -50, 0, +70,$   
and  $+125$  in the SAW resonator according to the present  
invention.

[Fig. 7] Fig. 7 is a diagram showing a relationship between  
5 a product  $H/\lambda \times m_r$  of the electrode film thickness and a line  
metalization ratio and the turnover temperature  $T_p$  in the SAW  
resonator according to the present invention.

[Fig. 8] Fig. 8 is a diagram showing a relationship between  
the cut angle  $\theta$  and the product  $H/\lambda \times m_r$  of the electrode film  
10 thickness and the line metalization ratio, when the turnover  
temperature  $T_p$  ( $^{\circ}\text{C}$ ) in the SAW resonator according to the present  
invention satisfies  $T_p = -50, 0, +70,$  and  $+125$ .

[Fig. 9] Fig. 9 is a diagram for explaining a two-port SAW  
resonator according to the present invention.

15 [Fig. 10] Figs. 10 are diagrams for explaining DMS filters  
according to the present invention, where Fig. 10(a) is a  
diagram showing a lateral coupling type DMS filter, and Fig.  
10(b) is a diagram showing a vertical coupling type DMS filter.

[Fig. 11] Fig. 11 is a diagram for explaining a ladder type  
20 SAW filter according to the present invention.

[Fig. 12] Figs. 12 are diagrams for explaining transversal  
SAW filters according to the present invention, where Fig. 12(a)  
is a diagram showing a transversal SAW filter where IDTs  
exciting a SAW in both directions are disposed, and Fig. 12(b)

25 is a diagram showing a transversal SAW filter where IDTs

exciting a SAW in one direction are disposed.

[Fig. 13] Fig. 13 is a diagram for explaining a conventional ST cut quartz SAW resonator.

[Fig. 14] Figs. 14(a) and 14(b) are diagrams for explaining  
5 a  $-50^\circ$  rotation Y cut  $90^\circ$  X propagation quartz substrate.

[Fig. 15] Fig.15 is a diagram for explaining a conventional multi-pair IDT type SAW resonator.

#### EXPLANATION OF THE CODES

[0065]

10	1	Piezoelectric substrate
	2	IDT
	3a, 3b	Grating reflector
	4a, 4b	Input/output pad
	5a, 5b	Metal wire
15	6	Package
	31	Piezoelectric substrate
	32, 33	IDT
	34a, 34b	Grating reflector
	41	Piezoelectric substrate
20	42	SAW resonator
	51	Piezoelectric substrate
	52	IDT
	61	Piezoelectric substrate
	62	One-port SAW resonator
25	71	Piezoelectric substrate
	72	Input IDT



- 73     Output IDT
- 74     Shielding electrode
- 75     Sound absorbing material
- 82, 83     Single phase uni-directional transducer

5